(54) Title: ELECTROENCEPHALOGRAPHIC CONSCIOUSNESS AND ANAESTHETIC MONITOR
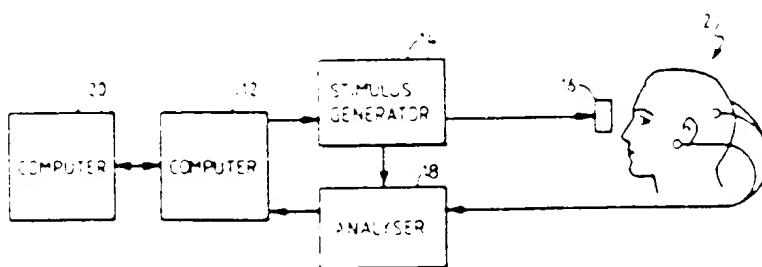
(57) Abstract

A method and apparatus for testing the anaesthetic depth or consciousness of a subject by directing visible light stimulus signals at the eyes of the subject through closed eyelids at accurately known frequencies. An electroencephalographic (EEG) signal is then obtained and a discriminator is used to accurately detect components at the applied frequencies. An assessment is then made by comparing the magnitude or phase of the components of the EEG signal at the predetermined frequencies with corresponding obtained EEG signals which have been obtained prior to administration of anaesthetic to the subject.

ELECTROENCEPHALOGRAPHIC CONSCIOUSNESS AND ANAESTHETIC MONITOR

This invention relates to an anaesthetic monitor.

More particularly the invention relates to a method
and apparatus for monitoring the level of consciousness
of a subject who has been subjected to a general
5   anaesthetic. Information concerning anaesthetic depth
and the level of consciousness would be of considerable
usefulness to the person administering the anaesthetic
so that the administration of the anaesthetic can be
controlled so as to give a desired anaesthetic depth and
10   level of consciousness.

According to the present invention there is
provided a method of testing anaesthetic depth or
consciousness of a subject comprising the steps of
applying a stimulus signal including at least one
15   component of a predetermined frequency to a sensory
organ of the subject, obtaining an
electroencephalographic (EEG) signal from the subject
whilst said stimulus signal is being applied, analysing
the EEG signal so as to determine the magnitude and/or
20   phase of that component of the EEG signal which has said
predetermined frequency, and assessing the anaesthetic
depth or consciousness of the subject with reference to
said magnitude and/or phase of the component.

2

Preferably, the method includes steps for applying a stimulus signal having a plurality of predetermined frequency components therein and the analysis of the EEG signal is carried out to determine the magnitude and/or
5   phase of the respective components in the EEG having the same frequencies as the stimulus signal.

Preferably further, the method includes the step of simultaneously applying selected groups of said frequency components.

10   Preferably further, the stimulus signal comprises electromagnetic radiation. Preferably further, the radiation comprises visible red radiation modulated in amplitude so as to have components at said plurality of predetermined frequencies. Preferably further, the
15   frequency components are in the range of 4 to 72 Hz. The method may be used to test the consciousness of a subject under anaesthetic and, in this application, the method includes the step of administering anaesthetic in accordance with the magnitude and/or phase of the
20   components.

In this case, the preferred method of treating the subject is to subject the subject to the method prior to administration of the anaesthetic so as to determine a pre-anaesthetic magnitude and/or phase response of the
25   selected component of the EEG signal (hereinafter called a normal response). The anaesthetic is then administered and the method includes the step of comparing the magnitude after administration of the anaesthetic to the normal response. The comparisons are preferably carried out and displayed as a function of frequency of the stimulus signal.

3

The invention also provides apparatus for testing
consciousness of a subject, said apparatus comprising
generator means for generating a stimulus signal having
at least one component of a predetermined frequency,
5   coupling means for coupling the stimulus signal to a
sensory organ of the subject, EEG electrodes for
deriving an EEG signal from the subject and
discriminating means for obtaining the magnitude and/or
phase of that component of the EEG signal which has said
10 predetermined frequency.

Where the apparatus is to be used for testing the
consciousness of a subject under anaesthetic, it is
important that the apparatus yields the information
quickly regarding the magnitude and/or phase of the
15 selected frequency component of the EEG signal so that
personnel administering the anaesthetic will be in a
position to monitor the results and thereby control the
rate of administration of the anaesthetic to the
subject.

20 The invention will now be further described with
reference to the accompanying drawings, in which:

Figure 1 is a block diagram showing the basic
components of the anaesthetic monitoring system of the
invention;

25 Figure 2 is a schematic plan view showing EEG
electrodes and Light Emitting Diode (LED) arrays
relative to a subject;

Figures 3A to 3D illustrate graphical output
displays of the system;

4

Figure 4 is a block diagram showing the stimulus generator;

Figure 5 is a more detailed circuit diagram of part of the stimulus generator;

5   Figure 6 is another circuit diagram of part of the stimulus generator;

Figure 7 is a circuit for controlling the intensity of an LED array;

Figure 8 is a schematic view of an LED array;

10   Figure 9 is a schematic side view of the LED array with shielding;

Figure 10 is a block diagram showing the EEG analyser;

Figure 11 is a circuit diagram of part of the
15   analyser;

Figure 12 is another circuit diagram of part of the analyser;

Figures 13A to 13G shows waveforms useful in understanding the operation of the invention;

20   Figure 14 is a block diagram of a microprocessor used in the system; and

Figure 15 is a schematic diagram of components associated with the microprocessor.

5

The system schematically illustrated in Figure 1 is
used for determining the state of awareness or
anaesthetic depth of a subject 2 who might for instance
be undergoing a surgical operation. An EEG signal from
5   the subject is obtained by using EEG electrodes 4, 6, 8
and 10.

Figure 2 shows one way in which the electrodes are
coupled to the head of the subject 2. In this
arrangement the electrode 4 is coupled to the forehead
10   of the subject and is used as a ground. The electrode 6
is coupled at the central occipital site (Oz) and the
electrodes 8 and 10 are connected to the ears of the
subject. The electrodes 8 and 10 and electrically
connected together and form the negative input for the
15   analyser, as will be described hereinafter.

The system includes a microcomputer 12 coupled to a
stimulus generator 14 which in turn is coupled to a pair
of LED arrays 16. The LED arrays are in use located
adjacent to the eyes of the subject 2 and are arranged
20   to generate signals which are perceptible through the
closed eyelids of the subject. The system includes an
analyser 18 which analysers the EEG signals obtained
from the electrodes 4, 6, 8 and 10. Output from the
analyser is coupled to the microcomputer 12. The
25   computer 12 arranges for further processing of the
output of the analyser in a general purpose computer 20
which may include a VDU display for display of results
in numerical or graphical form.

Generally speaking, the stimulus generator
30   generates a stimulus signal which comprises one or a
group of accurately known frequency components. The

6

stimulus signal is applied to the pair of LED arrays so
as to modulate the intensity thereof. The electrical
response of the brain of the subject is sensed using the
EEG electrodes and the analyser 18 very accurately
5   isolates the components which have the same frequency or
frequencies as the stimulus signal produced by the
stimulus generator 14. It has been found that this
technique enables very useful information to be obtained
regarding the anaesthetic depth of a subject. It has
10   also been found that certain frequencies are especially
useful in ascertaining the anaesthetic depth of the
subject but the peak sensitivity of some subjects occurs
at different frequencies. Accordingly, the preferred
technique of the invention involves applying signals to
15   the subject at a range of frequencies. In order to
conserve time, a group of say three selected frequencies
are applied simultaneously to the subject and the
analyser 18, microcomputer 12 and computer 20 are
arranged to separately analyse the response to the
20   individual frequencies in the selected group. Table 1
below sets out a typical selection of frequencies.

7

TABLE 1

GROUP	F_1 (Hz)	F_2 (Hz)	F_3 (Hz)	Duration	Typical Sensitivity
1	4	5	6	20 sec	reasonable
2	7	8	9	20 sec	reasonable
3	10	11	12	40 sec	not very selective
4	13	14	15	20 sec	not very selective
5	16	17	18	10 sec	satisfactory
6	20	22	24	10 sec	satisfactory
7	26	28	30	10 sec	satisfactory
8	32	34	36	10 sec	satisfactory
9	38	40	42	10 sec	best
10	44	46	48	10 sec	best
11	50	52	54	10 sec	best
12	56	58	60	10 sec	best
13	62	64	66	10 sec	best
14	68	70	72	10 sec	best

The table indicates that there are fourteen groups of frequencies F_1, F_2 and F_3, the duration for which the group of frequencies is applied and the typical sensitivity of a subject to those particular frequencies. The duration is chosen so that a

8

reasonably accurate EEG response can be obtained, e.g. a signal to noise ratio of 3dB in a relatively short period. In the period were too long, the system would not yield results quickly enough for monitoring the

5 anaesthetic depth of a subject under an anaesthetic. The selection of frequencies within the groups is arbitrary but for convenience the frequencies F_1, F_2 and F_3 are adjacent so that the optimum durations are also similar. It has been found that for signals above about

10 72 Hz the EEG response is too small.

In carrying out the invention, the subject is first subjected to signals from the stimulus generator 14 before any anaesthetic is administered so as to obtain an "awake" response because the EEG amplitudes of

15 subjects vary quite considerably from one to another. The awake response is stored in the general purpose computer 20 so that normalized results can be displayed when the subject is subjected to the stimulus under anaesthetic.

20   Figure 3A illustrates the typical EEG magnitude response of a subject as a function of frequency. The solid line 22 shows the "awake" response which is obtained before any anaesthetic is administered, the red light signals being applied through the closed eyelids

25 of the subject as mentioned previously. The graph also shows the "asleep" response 24 as a function of frequency after a subject has been subjected to the anaesthetic. The general purpose computer 20 can be programmed to display a graph in a similar format to

30 that shown in Figure 3A, the asleep response 24 being continually updated by results obtained from the analyser 18 and microcomputer 16. An operator can then

make a comparative assessment to see the ratio of the asleep response 24 to the awake response at a particular frequency. Generally speaking, a useful indication is that the subject is soundly anaesthetized is when the

5 asleep response is less than 50% of the awake response.

Alternatively, the general purpose computer 20 can be programmed to display the output information as a function of time. Figure 3C shows the magnitude responses as a function of frequency, the general

10 purpose computer 20 being preprogrammed to integrate to obtain the area A_1 beneath the awake response 26 in a selected frequency range say 40 to 72 Hz and to integrate so as to obtain the area A_2 beneath the asleep response 28. The ratio response 30 can then be

15 displayed as a function of time as shown in Figure 3D. Output in this form provides a very convenient indication to an operator of the anaesthetic depth of the subject. Where the ratio response 30 is less than 0.5, that can be taken as an indication that the subject

20 is sufficiently anaesthetized.

It would be possible of course to arrange to automatically control the administration of further anaesthetic into the subject in accordance with the normalized response information available in the

25 computer 20. For safety reasons however it is envisaged that the administration of further anaesthetic would be carried out manually after assessment of the output of the computer by an experienced operator.

In an alternative arrangement, the phase response

30 of the subject could be obtained and utilized in a similar way. For instance, whilst the subject were

10

awake, the phase response of the selected frequency
components in the EEG relative to the respective
frequency components generated by the stimulus generator
could be obtained and stored as a function of frequency.

5   Figure 3B shows the awake response 32 of the phase
difference as a function of frequency. The asleep
response 34 is also shown. The phase response is
proportional to frequency multiplied by T where T is the
delay between input of a stimulus and the EEG response.

10 It has been found that the delay T of a subject varies
in accordance with the anaesthetic depth and thereby
this parameter can be used for assessment of the
anaesthetic depth.

        Figures 4 to 15 illustrate in more detail a
15 preferred arrangement for the stimulus generator 14,
analyser 18 and microcomputer 12.

        Figure 4 shows an oscillator 36 arranged to
oscillate at say 4 MHz. The output of the oscillator 36
is coupled to a divider 38 the output of which is
20 coupled to frequency multipliers 40, 42 and 44 the
outputs of which are coupled to counters 46, 48 and 50
respectively. The outputs of the counters 46, 48 and 50
comprise square-wave signals, the frequencies of which
are accurately determined and comprise the frequency
25 components F_1, F_2 and F_3 to be applied to the subject in
accordance with Table 1 above. The actual values of the
frequencies produced by the multipliers 40, 42 and 44
are determined in accordance with data input on data
lines 52, 54 and 56 from the microcomputer 12. Output
30 from the counters 46, 48 and 50 is applied to ROM's 58,
60 and 62. Each of the ROM's has three functions.
First to store a lookup table for sine values and so

12

produce output in digital form on lines 64, 66 and 68,
the output being the sine of the number applied to the
respective ROM. The ROM's also have cosine look-up
tables so as to produce cosine outputs on lines 70, 72
5   and 74. The ROM's also produce control signals on lines
76, 78 and 80 which are applied to the analyser 18. The
sine output lines 64, 66 and 68 are coupled to digital
to analogue converters 82, 84 and 86 the outputs of
which are summed in an adding circuit 88. The summed
10   output from the summer 88 is applied to an LED control
circuit 90 which produces current for the LED arrays 16.
Thus, the current signal applied to the LED array 16 has
three accurately known frequency components F_1, F_2 and
F_3 as determined by the microcomputer 12.

15   Figure 5 shows in schematic form a circuit
realization for part of the stimulus generator 14. In
this arrangement, the oscillator 36 is a 4 MHz crystal
oscillator and its output is coupled to the input of the
counter 38 by means of a buffer amplifier 92. The
20   divider 38 conveniently comprises a 4040 counter
receiving output from the buffer amplifier 92. The
output from the counter comprises a stable accurately
defined frequency which for convenience is chosen to be
512 Hz. The output signal is connected to the inputs of
25   the frequency multipliers 40, 42 and 44, the multiplier
40 being shown in more detail in Figure 6 by way of
example. The multiplier 40 comprises a 4046
phase-locked loop circuit 94 which receives output from
the counter 38, via pin 14. The circuit includes a
30   divider circuit 96 the output of which is coupled via
line 98 to pin 3 of the 4046 circuit. The divider
circuit itself includes presettable down counters 100
and 102 each of which comprises a 74 LS 191 circuit.

12

The divider circuit operates to divide by a number read
into a 74 LS 373 eight-bit latch 104 from the
microcomputer 12 via lines 52. Thus the input to the
latch 104 determines the factor by which the divider 96
5   divides the reference frequency input to the frequency
multiplier 40. The output of the multiplier 40 appears
on line 106 which is coupled to the input of counter 46.
The frequency is 1024 times the frequency F_1. The
counter 46 comprises a 74 LS 393 counter arranged to
10 divide the input by the factor 1024 whereby its output
is at frequency F_1.

As seen in Figure 6, the counter 46 has its ten-bit
output coupled to the inputs of ROM 58 which preferably
comprises three ROM elements 106, 108, 110 each having
15 eight output bits. Eight bits of the element 106 and
two from the element 108 are used for the sine output
table, and eight bits from the element 110 and two the
element 108 are used for the cosine output table. The
remaining four bits of the ROM element 108 are connected
20 to the control lines 76 for control signals for the
microcomputer 12 and for the analyser 18. The ten-bit
sine output from the ROM 58 is then coupled to the input
of a digital to analogue converter 80 and the output 112
is connected to one input of the adding circuit 88. The
25 adding circuit comprises a differential amplifier 114
the positive input of which is grounded and the output
of which has a resistive feedback element 116 connected
to the summing junction 118 which in turn is coupled to
the negative input of the amplifier 114. The amplifier
114 may comprise a TL 071 circuit. The other inputs to
the adding circuit 88 are derived from the digital to
analogue converters 84 and 86 which relate to the
reference frequencies F_2 and F_3 respectively.

13

Output from the amplifier 114 is coupled to input line 120 of the LED control circuit 90, as shown in Figure 7. The input line 120 is coupled to the input of an amplifier 122 via a zero adjusting network 124 which
5 is adjusted so that the output of the circuit 90 has a desired DC level. Output from the amplifier 122 is coupled to the input of a current buffer 126 for driving the LED arrays 16. Each array 16 comprises seven LED devices 128 arranged in a circular pattern, as
10 diagrammatically illustrated in Figure 8. The fourteen LED's are connected in series and are driven by the current supplied from the buffer 126. The other end of the series connection of LED's is connected to a negative supply line 130 the voltage of which is
15 selected in accordance with the number of LED's connected in series. In order to regulate the intensity of the output of the array 16, a control LED 132 is connected in series with the output of buffer 126 and arranged to irradiate a phototransistor 134, the output
20 of which is connected via amplifier 136 to the input of the amplifier 122. The output of the control LED 132 which is selected so as to be of the same type as those used in the array 16 is thus representative of the light intensity output of the array and this is used for
25 negative feedback so as to control the peak intensity reached by the LED arrays 16. The circuit 90 thus ensures a constant average level of intensity of light output from the LED array 16 regardless of which selected group of reference frequencies is applied to
30 the LED arrays.

In one arrangement, it was found convenient to use LED devices manufactured by Stanley known as ESBR diodes. The current flowing through the diodes is

14

typically 20 to 30 milliamps and less than 50 milliamps.
The zero adjust network 124 ensures that the LED devices
are not reversed biased at any stage in the process
because this would have the effect of upsetting the
5   otherwise purely sinusoidal inputs to the LED devices.

It has been found desirable to locate the LED
arrays 16 within inner and outer shielding screens 138
and 140 as shown in Figure 9.   The screens substantially
eliminate the effects of electric and magnetic fields
10   produced by the currents flowing through the LED's 128.
The conductors 142 to the array 16 are also shielded for
the same reason.   Shielding is very important from a
practical point of view because of the proximity of the
array 16 to the EEG electrodes and because of the
15   relatively low signal level, i.e. signals at the
selected frequencies F_1, F_2 and F_3 compared to the
background EEG signal.   Typically the signal level at
the reference frequencies might be less than 2
microvolts whereas the background level could be 20
20   volts.

Figure 10 illustrates in more detail the analyser
circuit 18.   It comprises an input amplifier 144 which
receives an EEG signal from the electrodes 4, 6, 8 and
10.   Output from the amplifier passes to a band pass
25   filter 146 selected to pass frequencies say in the range
1 to 100 Hz.   Output from the filter 146 is coupled to
the inputs of multiplying digital to analogue converters
148, 150, 152, 154, 156 and 158.   Other inputs to the
converters are from the ROM's 58, 60 and 62 of the
30   stimulus generator 14.   The sine output lines 64, 66 and
68 are connected to the converters 148, 150 and 156
respectively.   The cosine output lines 70, 72 and 74 are

15

connected to the converters 150, 154 and 158
respectively. The outputs of the converters are coupled
to the inputs of integrators 160, 162, 164, 166, 168 and
170, the outputs of which are coupled to sample and hold
5   circuits 172, 174, 176, 178, 180 and 182 respectively.
The integrators and sample and hold circuits are
controlled by output signals from the ROM's of the
generator 14. More particularly, the integrators 160
and 162 and sample and hold circuits 172 and 174 are
10   controlled by the control lines 76 from the ROM 58 and
are thus used for analysis at the reference frequency
F_1. The integrators 164 and 166 and sample and hold
circuits 176 and 178 receive control signals via the
lines 78 from the ROM 60 and are used for reference
15   frequency F_2. The integrators 168 and 170 and circuits
180 and 182 are controlled by signals on the control
line 80 from ROM 62 and are used for reference frequency
F_3. Outputs from the sample and hold circuits are
coupled to an analogue to digital converting device 184
20   via a multiplexer 186 which in turn is controlled by the
microcomputer 12 via line 187. The converting device
184 is controlled by the microcomputer 12 via control
lines 189. Data output from the converter 184 is
applied to the microcomputer 12 for further processing.

25   Generally speaking, the arrangement of Figure 10 is
used to enable very accurate selection from the EEG
signal received by the amplifier 144 of components at
the reference frequencies F_1, F_2 and F_3. Further, the
discrimination can be performed in a relatively short
30   time so that information is available to the computer 12
to allow updating of displayed information at a
reasonable repetition rate.

16

Output signal of the filter 146 denoted f(t) will include components at the selected frequences F_1, F_2 and F_3. Considering firstly the frequency F_1, the output signals from the converters 148 and 150 will be as

5   follows:

output of converter 148 = $f(t).\mathrm{Sin}\ 2\pi f_1$
output of converter 150 = $f(t).\mathrm{Cos}\ 2\pi f_1$

because of the inputs from lines 64 and 70 from the ROM 58. The integrators 160 and 162 are arranged to

10   integrate the outputs from the converters 148 and 150 for a selected number of full cycles of the at the selected frequency F_1 as determined by control lines 76. Thus the outputs of the integrators 160 and 162 are as follows:

15   output of integrator 160 = $\int_0^{2\pi} f(t).\mathrm{Sin}\ 2\pi F_1.dt$

output of integrator 162 = $\int_0^{2\pi} f(t).\mathrm{Cos}\ 2\pi F_1.dt$

By Fourier analysis it can be shown that the magnitude M_1 of the component of the EEG signal f(t) at frequency F_1 can be calculated as follows:

20   $M_1 = \sqrt{[\int_0^{2\pi} f(t).\mathrm{Sin}\ 2\pi F_1.dt]^2 + [\int_0^{2\pi} f(t).\mathrm{Cos}\ 2\pi F_1.dt]^2}$

The output values of the integrators 160 and 162 at the end of each period of the frequency F_1 will be held in the sample and hold circuits 172 and 174 for conversion to digital from in the converter 184 and for transfer to the microcomputer 12 for averaging over the

17

required number of cycles indicated in Table 1. The averaged outputs of circuits 172 and 174 are then squared, summed and the square root obtained to determine the value M_1. For instance at $F_1=4Hz$, there are 80 cycles whereby the value of M_1 is averaged over these 80 cycles thus yielding a reasonably accurate result in a relatively short time.

5

The other selected frequencies F_2 and F_3 in the group are processed in a similar manner, the outputs of sample and hold circuits 176 and 178 being relevant to frequency F_2 and the outputs of sample and hold circuits 180 and 182 being relevant to frequency F_3.

10

The use of the multiplexer 186 under control of the microcomputer 12 enables a single analogue to digital converter 184 to be utilized. Thus the average values M_1, M_2 and M_3 of the frequency components at the frequencies F_1, F_2 and F_3 can be calculated and stored in the microprocessor 12. The stored information can then be transferred to the computer 20 and used to provide graphical output in the format as shown for instance in Figure 3A or Figure 3D.

15

20

If required, the phase change can also be computed for generating an output display of the type shown in Figure 3B. The phase difference can be calculated using the following formula:

25

18

$$\Delta\phi = \frac{\pi}{2} \left[1 - Sgn(B_n) \right] + Artan \frac{A_n}{B_n}$$

where $Sgn(B_n) = +1$ $0 \leqslant B_n$

$Sgn(B_n) = -1$ $B_n < 0$

and $A_n = \int_0^{N/f_1} f(t).Sin\ 2\pi F_1.dt$

5      $B_n = \int_0^{N/f_1} f(t).Sin\ 2\pi F_1.dt$

N = number of cycles at F_1 over which integration takes place

10   It will be appreciated that the coefficients A_n and B_n are directly related to the outputs of the sample and hold circuits 172 and 174 and are therefore readily available for determination and subsequent processing.

Similarly, the phase response for the frequencies F_2 and F_3 can be obtained from the sample and hold circuits 176, 178 and 180, 182 respectively.

15   The circuit of Figure 10 is particularly suitable in the arrangement of the invention because the analogue integrators 160-170 enable very rapid and accurate computation of the required integrals. The remaining mathematical processing is however most conveniently
20   done in digital form in the computers 12 and 20, it being largely a matter of convenience where the computations are performed.

Figure 11 illustrates in more detail the amplifier 144 and filter 146. The amplifier 144 comprises a
25   precision instrumentation differential amplifier (AMP-01) the negative input 188 of which is connected to

the electrodes 8 and 10 connected to the ear of the subject. The positive input 190 is connected to the electrode 6 at the central occipital site and the ground input 192 is connected to the electrode 4 at the

5   forehead of the subject. The inputs 188 and 190 include coupling capacitors 194 to filter out very low frequency components say below 1 Hz and can thus be regarded as part of the filter 146. Output from the amplifier 144 passes to a resistance-capacitance network which

10 comprises the remainder of the filter 146 and operates to attenuate frequencies above say 100 Hz. Output from the filter 146 is then amplified in a pair of amplifiers 196 and 198, the latter including a DC offset network 200 for adjustment of the DC output level of the

15 amplifier 198. The output of the amplifier 198 is coupled to the input of a further amplifier 202 via an optocoupler 204. The optical coupling is particularly important because the amplifier 144 is directly coupled to the head of the subject via the EEG electrodes and

20 for safety reasons it is important to use a battery for the power supply for the amplifiers 144, 196 and 198. The use of the optocoupler 204 ensures that these components are not electrically connected with the remainder of the circuit which can be powered from a

25 mains supply. It follows that should there be any equipment malfunction, there is very little likelihood of excessively high voltages or currents being applied to the subject.

    Figure 12 shows in more detail a circuit

30 realization for the arrangement shown in Figure 10. Output from the amplifier 202 is applied to input line 206 which is connected to the reference inputs of the multiplying digital to analogue converters 148 and 140

20

which may comprise type 7520 circuits. The converter

148 receives the sine signal on lines 64 from the ROM 58

whereas the converter 150 receives the cosine signal on

lines 74 from the same ROM. The converters 148 and 150

5   thus produce products in analogue form proportional to

the EEG signal multiplied by the sine and cosine

functions at reference frequency F_1. The output from

the converter 148 passes to the input of the integrator

160 which comprises a TL 072 amplifier having an input

10   resistor 208 and feedback capacitor 210 so that the

amplifier functions as an analogue integrator in the

usual way. The capacitor 210 is bridged by an analogue

switch 212, which is of type 4066, and receives control

signals on control line 76a from the ROM 58. The

15   waveform of the control signal on the line 76a is

represented by waveform 214 in Figure 13D. The waveform

214 closes the switch 212 which results in rapid

discharging of the capacitor 210 at or just after the

zero crossings of the reference frequency F_1 which is

20   represented by waveform 216 in Figure 13A. The sample

and hold circuit 172 is controlled to hold the value of

the integrator just prior to its being discharged on

closing of the switch 212. This is effected by control

signals on control line 76b which have the waveform 218,

25   as shown in Figure 13E. Figures 13F and 13G show the

sequence of the control signals on lines 76a and 76b

respectively on an expanded time scale. It will be seen

that the negative going pulse 220 which actuates the

sample and hold circuit 172 occurs prior to the positive

30   going pulse 222 which causes closure of the switch 212.

When the sample and hold circuit 172 receives the

leading edge of the pulse 220 it causes the circuit 172

to track the output of the integrator and the trailing

edge triggers the start of the holding cycle. Figure

13B illustrates a typical output waveform 224 of the integrator 160 and Figure 13C shows a typical output waveform 226 of the sample and hold circuit 172. It will be observed in the waveform 226 that the tracking

5   period occurs just prior to the zero crossings of the reference frequency F_1. Thus, the output waveform 226 of the circuit 172 during each cycle of the reference frequency F_1 represents the value of the integral at the output of the integrator 160 at the end of each cycle.

10   An analogous waveform is obtained at the output of the sample and hold circuit 174 for the cosine product integral. The outputs from the circuits 172 and 174 are connected to the multiplexer 186 via lines 175 and 177 for processing as described previously. Similar

15   circuitry is also provided for the reference frequencies F_2 and F_3 so as to enable simultaneous processing of three reference frequencies.

Figure 14 illustrates schematically one configuration for the microcomputer 12. It comprises a

20   6082 series CPU 228, two 2732 PROM's 230 and 232, and a 6116 RAM 234. The circuit includes a selector 336 for providing address decode information for the frequency multipliers 40, 42 and 44 i.e. data for the latch 104 shown in Figure 5 in relation to reference frequency F_1.

25   The circuit includes three input/output units 338, 340 and 342 for providing communication with the components in the stimulus generator 14 and analyser 18. The circuit includes an RS 232 interface connector 344 for coupling to the general purpose microcomputer 20.

30   Figure 15 shows in diagrammatic form three flip flops 346, 348 and 350 used to flag various service requests required for the operation of the stimulus

22

generator 14 and analyser 18. The outputs of the flip
flops are inputted to the input/output unit 340 via
lines 352 and 354, as seen in Figure 14.

5   The principles of the invention disclosed herein
are applicable to other sensory organs such as the ears
of a subject so as to enable assessment of consciousness
of the subject.

         Many modifications will be apparent to those
skilled in the art without departing from the spirit and
10 scope of the invention.

23

CLAIMS

1.   A method of testing anaesthetic depth or conscious-
ness of a subject (2) comprising the steps of applying a
stimulus signal (216) including at least one component
of a predetermined frequency (F_1, F_2, F_3) to a sensory
organ of the subject, obtaining an
electroencephalographic (EEG) signal from the subject
whilst said stimulus signal is being applied, analysing
the EEG signal so as to determine the magnitude and/or
phase of that component of the EEG signal which has said
predetermined frequency, and assessing the anaesthetic
depth or consciousness of the subject with reference to
said magnitude and/or phase of the component.

2.   A method as claimed in claim 1 including the step
of applying a stimulus signal having a plurality of
predetermined frequency components therein and the
analysis of the EEG signal is carried out to determine
the magnitude and/or phase of the respective components
in the EEG having the same frequencies as the stimulus
signal.

3.   A method as claimed in claim 1 including the step
of simultaneously applying selected groups of said
frequency components.

4.   A method as claimed in any preceding claim
including the step of obtaining a normal response (22,
32) for the subject by obtaining a normal
electroencephalographic (EEG) signal from the subject
prior to administering anaesthetic to the subject, and
wherein said step of assessing the anaesthetic depth or

24

consciousness includes the step of comparing the first
mentioned EEG signal with said normal EEG signal.

5.   A method as claimed in claim 4 including the step
of graphically displaying said EEG signals or a ratio
thereof (30).

6.   A method as claimed in any preceding claim wherein
said stimulus signal comprises electromagnetic radia-
tion.

7.   A method as claimed in claim 6 wherein the radia-
tion comprises visible red radiation modulated in
intensity so as to have components at said plurality of
predetermined frequencies.

8.   A method as claimed in claim 7 wherein the prede-
termined frequencies are in the range from 4 to 72 Hz.

9.   A method as claimed in claim 7 or 8 wherein said
red radiation is directed at the eye or eyes of the
subject through closed eyelids.

10.   A method as claimed in any preceding claim
including the step of administering anaesthetic to the
subject in accordance with the assessment of anaesthetic
depth.

11.   A method as claimed in claim 2 or 3 wherein the EEG
signal from the subject is separately multiplied by the
sine and cosine of each frequency component f_n of the
stimulus signal and then integrated as a function of
time, and the magnitude M_n of the EEG signal at

25

frequency f_n is determined by performing the following calculation:

$$M_n = \sqrt{[\int_o^{2\pi} EEG.Sin2\pi f_n.dt]^2 + [\int_o^{2\pi} EEG.Cos2\pi f_n.dt]^2}.$$

12. A method as claimed in claim 11 wherein the steps of multiplying by the sine and cosine of each frequency and the integration are performed in analogue form.

13. Apparatus for testing consciousness of a subject, said apparatus comprising generator means (14) for generating a stimulus signal having at least one component of a predetermined frequency, coupling means (16) for coupling the stimulus signal to a sensory organ of the subject, EEG electrodes (4, 6, 8, 10) for deriving an EEG signal from the subject and discriminating means (18) for obtaining the magnitude and/or phase of that component of the EEG signal which has said predetermined frequency.

14. Apparatus as claimed in claim 13 wherein the generator means generates a plurality of predetermined frequency components (F_1, F_2, F_3) which are, in use, simultaneously applied to the subject and the discriminating means determines the magnitude and/or phase of the respective components of the EEG signal.

15. Apparatus as claimed in claim 14 wherein the discriminating means includes a plurality of multiplier circuits (148-158) for separately multiplying the EEG signal by the sine and cosine of each frequency component f_n of the stimulus signal, and a plurality of integrator circuits (160-170) for integrating the outputs of the multiplier circuits.

16. Apparatus as claimed in claim 15 wherein the outputs of the integrator circuits are coupled to inputs of respective sample and hold circuits (172-182) which hold the output values of the integrator circuits at the end of each period of the frequency component f_n of the stimulus signal.

17. Apparatus as claimed in claim 16 wherein the outputs of the sample and hold circuits are averaged over a preselected number of cycles to obtain average values of sine and cosine integrals at each frequency component and wherein the discriminating means includes an arithmetic unit (12) for calculating the magnitude M_n of the EEG signal at frequency f_n by taking the square root of the sum of the squares of the respective average values at each frequency component f_n.

18. Apparatus as claimed in claim 17 including a multiplexer (186) and an analogue to digital converter (184) and wherein the outputs of the sample and hold circuits are coupled to the converter via the multiplexer and wherein said arithmetic unit performs its operations in digital form.

19. Apparatus as claimed in any one of claims 13 to 18 wherein the coupling means comprises an LED array (16) for applying intensity modulated infra red signals to the eye or eyes of the subject through his closed eyelid or eyelids.

20. Apparatus as claimed in claim 19 wherein the generator means includes an intensity control circuit (90) which regulates the peak intensity of light emitted from the LED array, said intensity control circuit including

a control LED (132) output from which provides negative
feedback for controlling driving current to the LED
array.

21. Apparatus as claimed in claim 19 or 20 wherein the
LED array is coupled to the intensity control circuit
via an optocoupler.

22. Apparatus as claimed in claim 21 wherein the LED
array is located within sheilding screen (138, 140).

23. Apparatus as claimed in any one of claims 19 to 22
wherein the LED array is in two portions which overlie
in use respective eyes of the subject.

24. Apparatus as claimed in claim 23 wherein said
portions are mounted on goggles or a spectacle frame.

FIG 1

FIG 2

FIG 3a

EEG MAGNITUDE

1·0

22
AWAKE

24
ASLEEP

20   40   60   80   Hz

FIG 3b

$\triangle \phi$

20   40   60   80   Hz

-4π
-6π
-8π

32
AWAKE

34
ANAESTHETIZED

FIG 3c

EEG MAGNITUDE

A1

26
AWAKE

28
ASLEEP

A2

20   40   60   72 80   Hz

FIG 3d

A_2 / A_1

1·0

·5

30

r

FIG 4

FIG 5

FIG 6
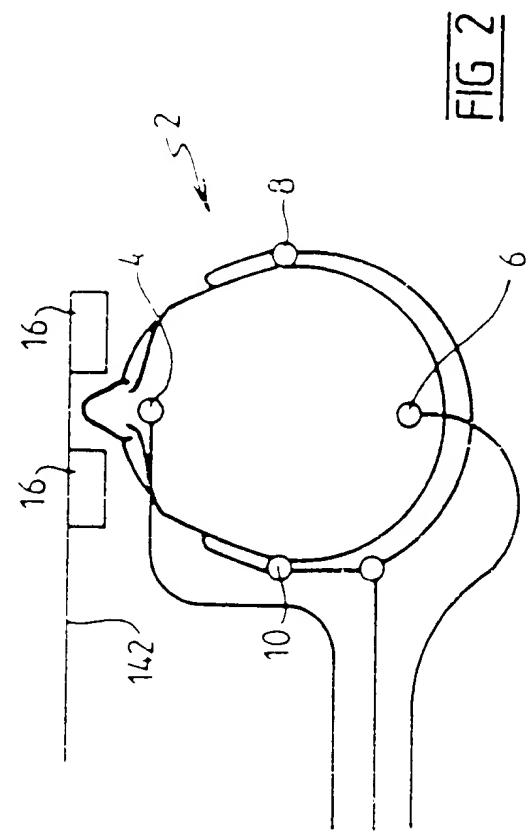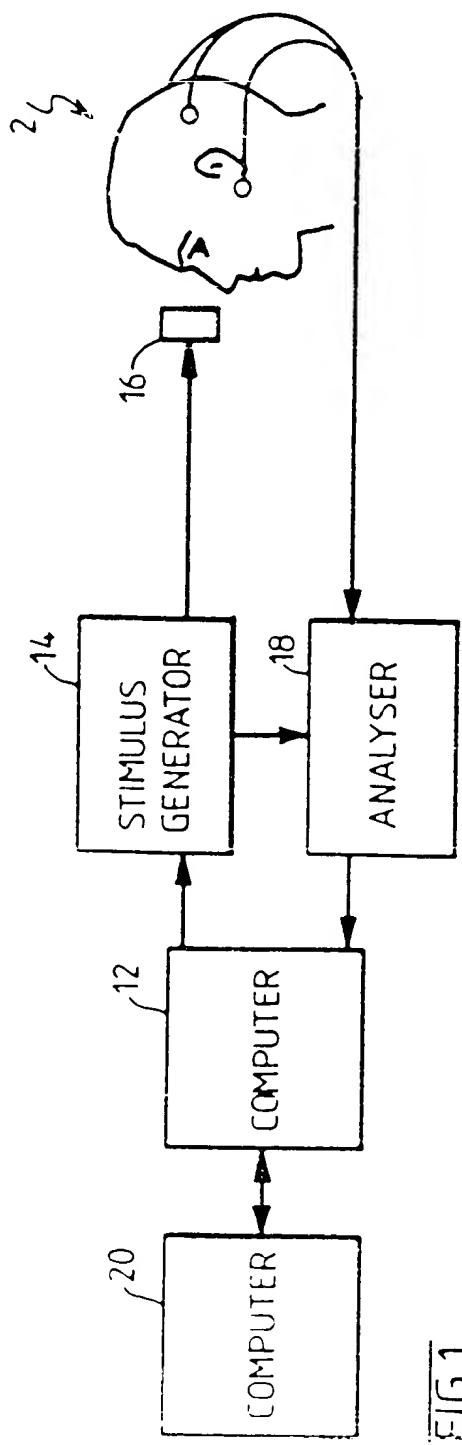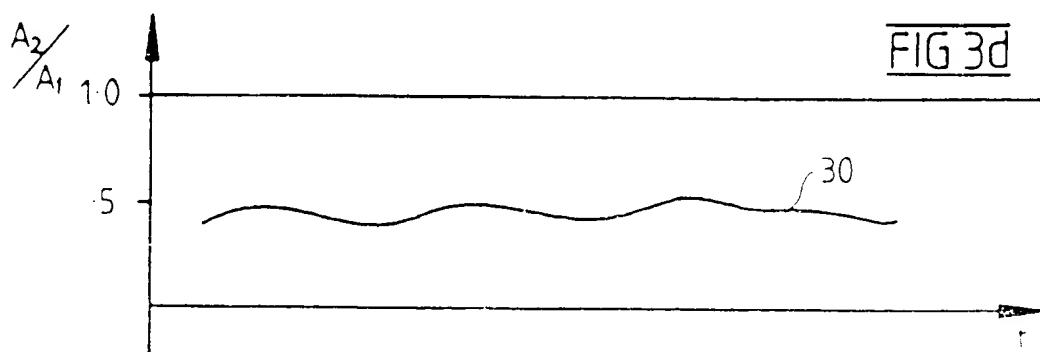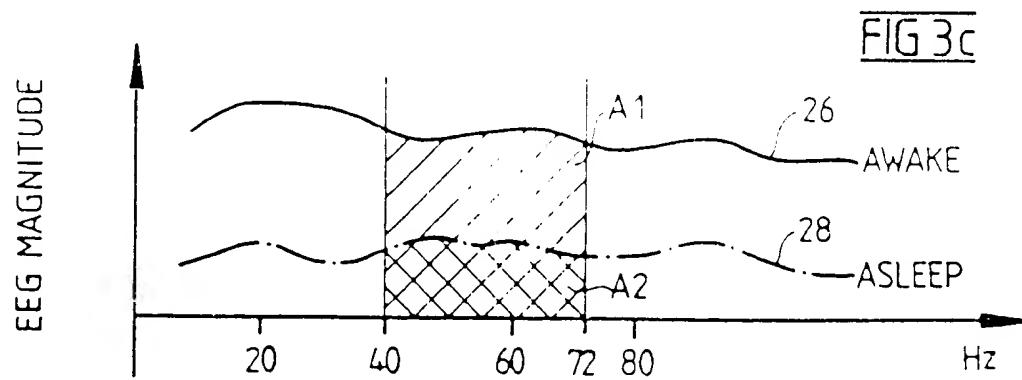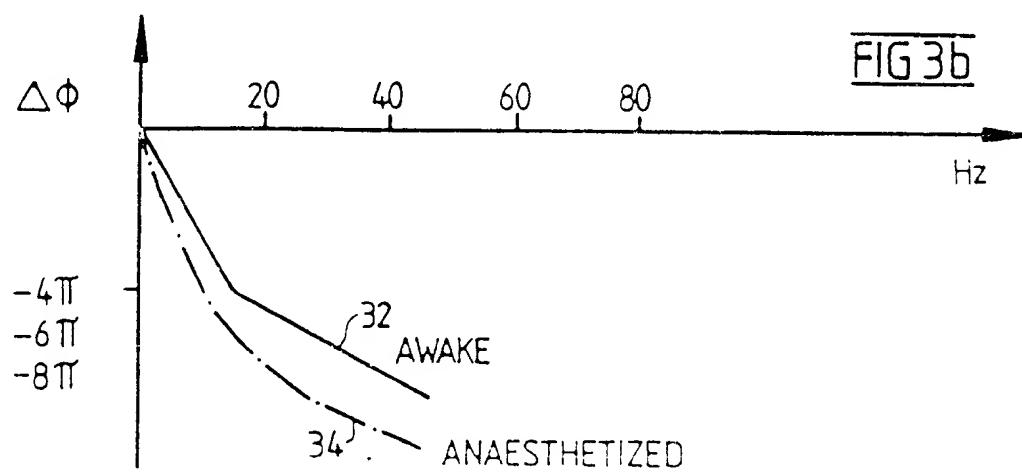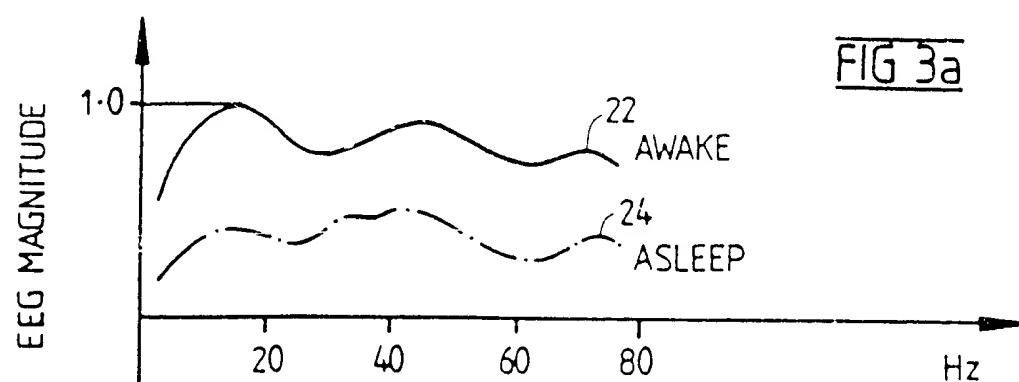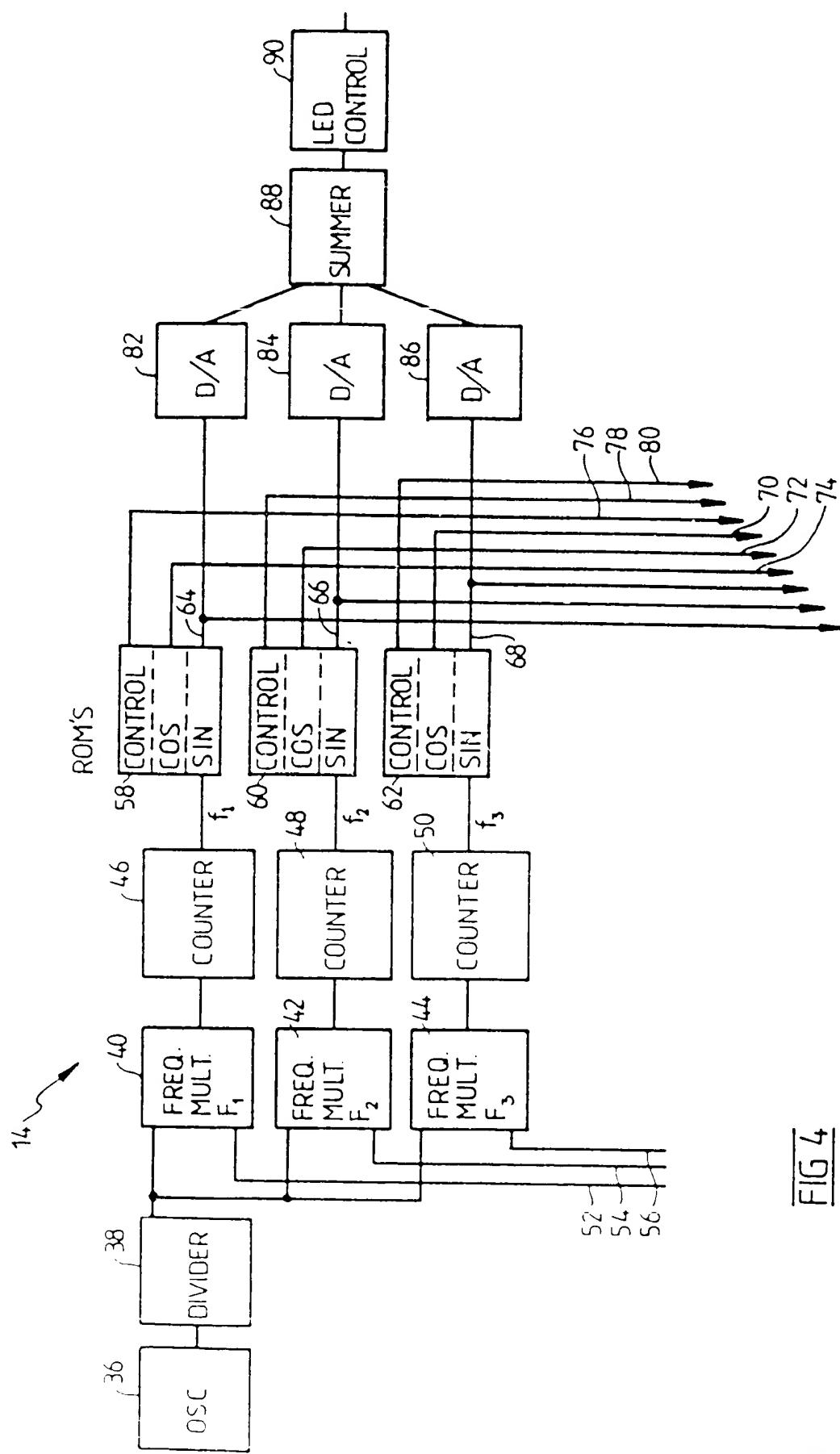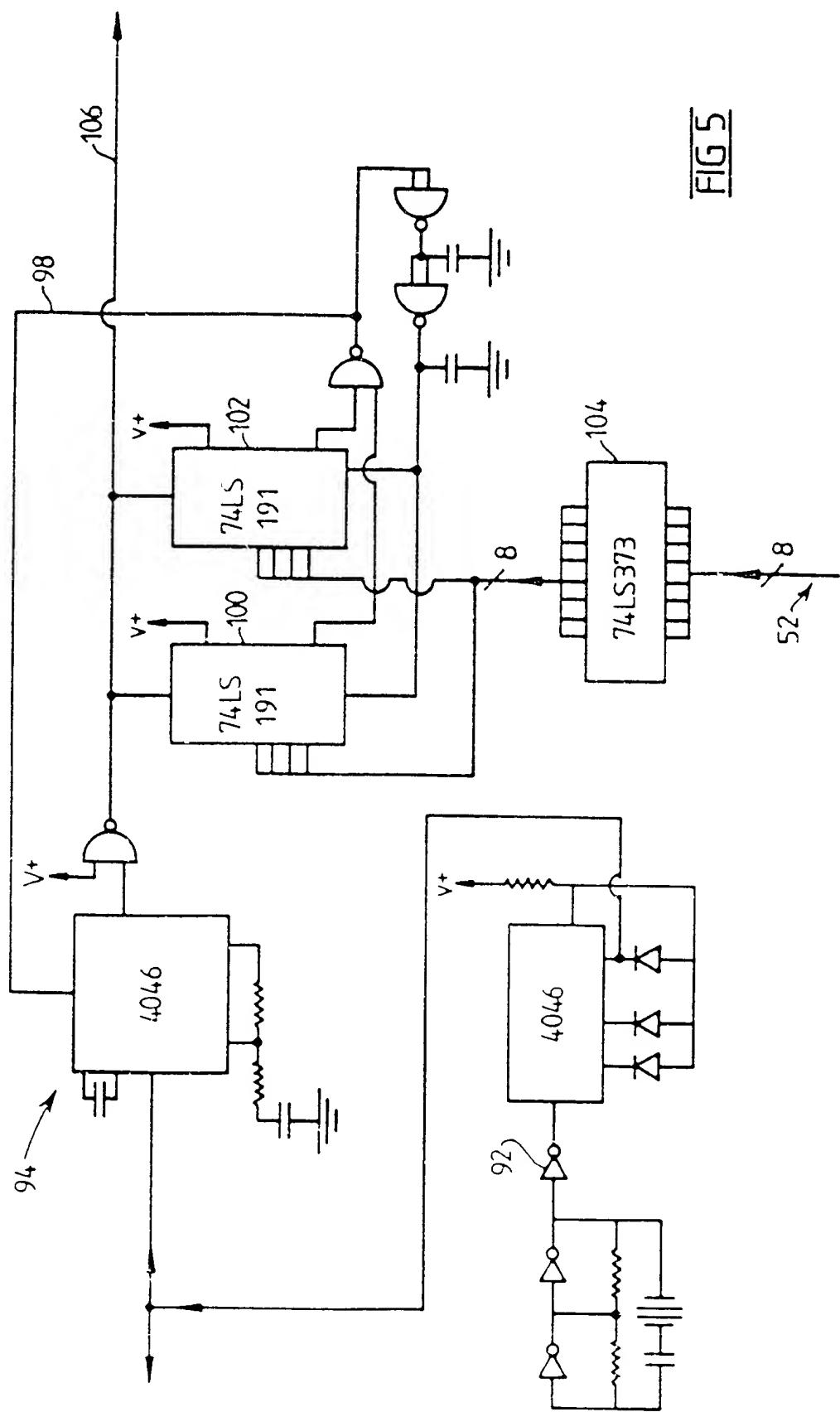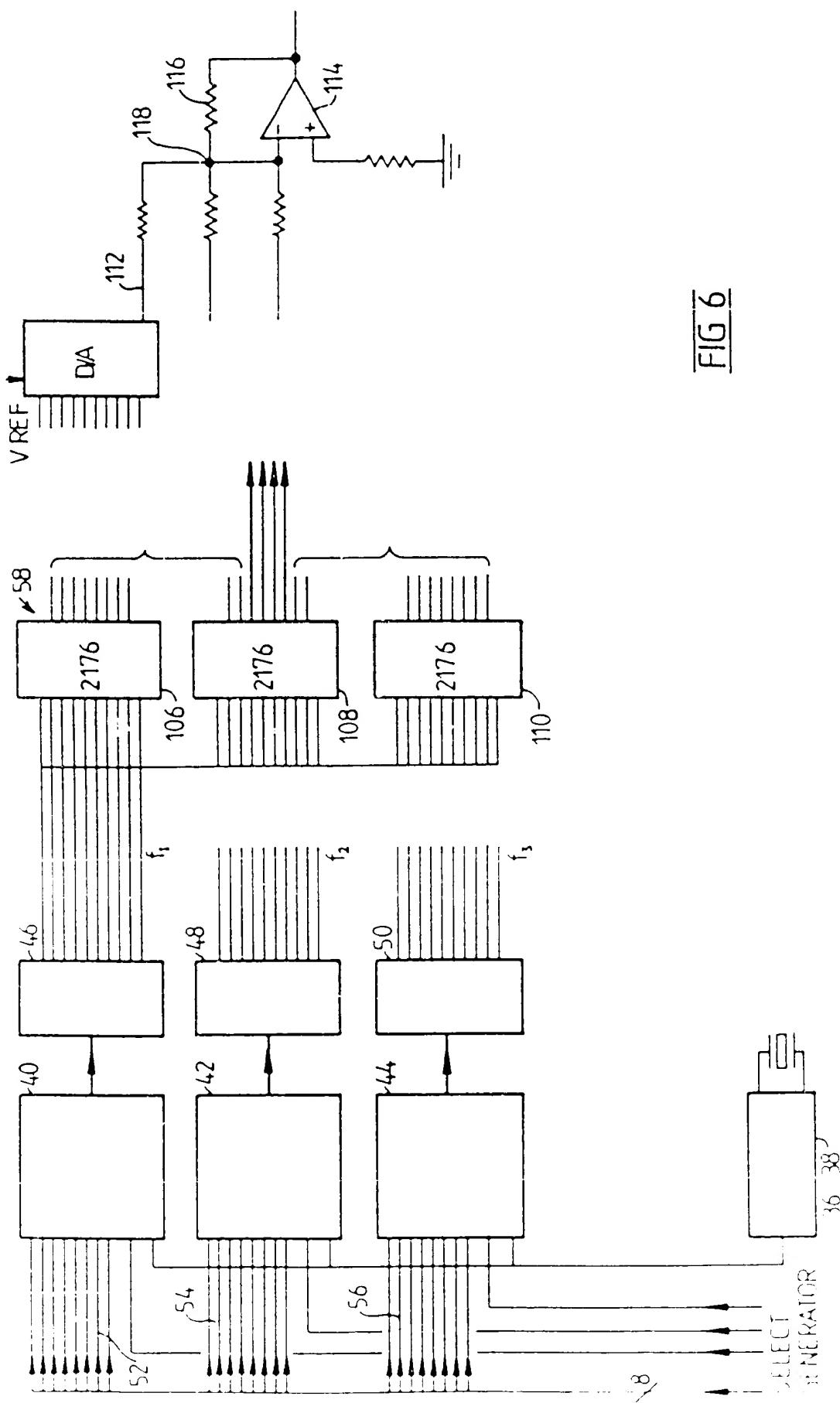
FIG 7
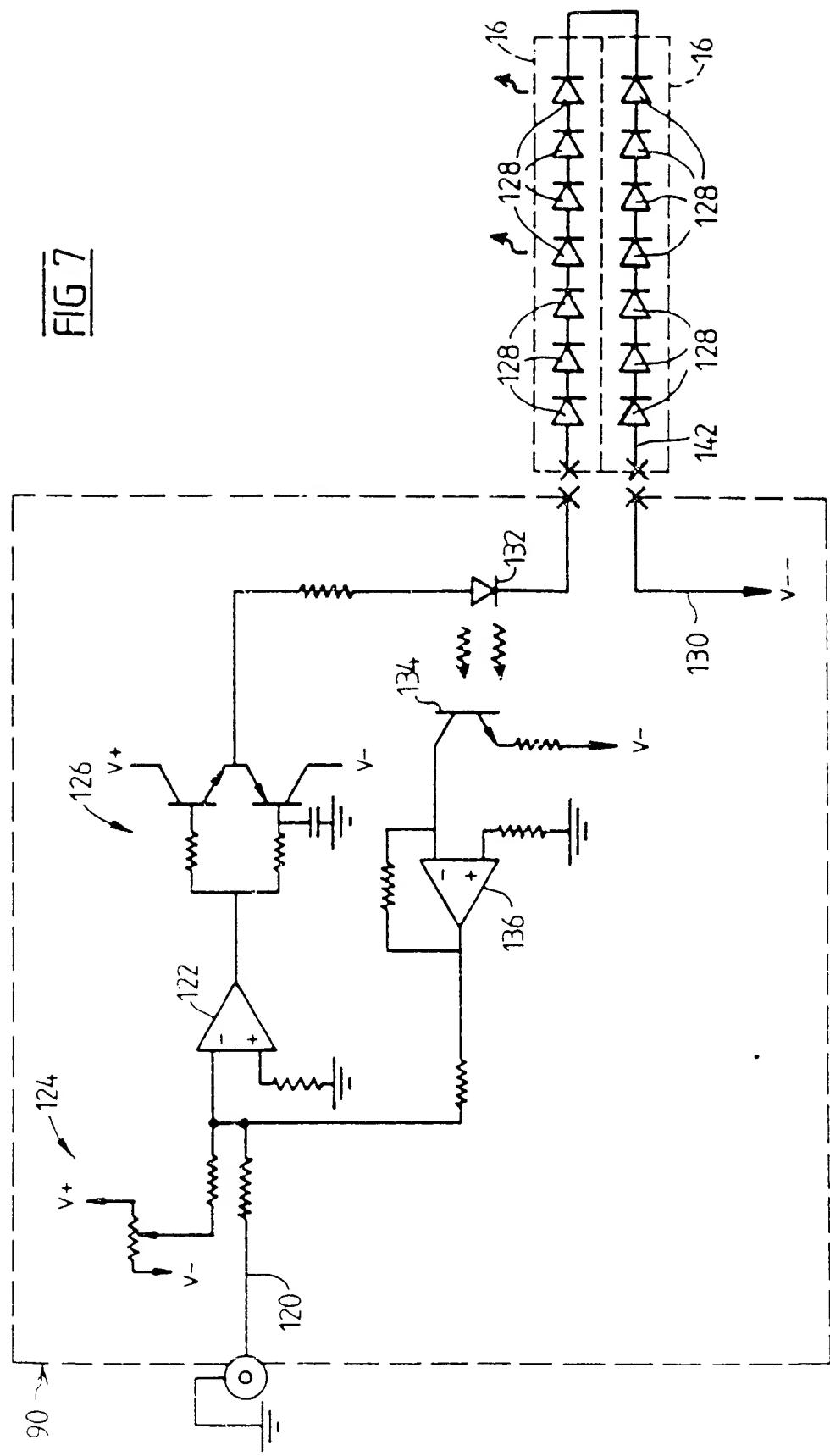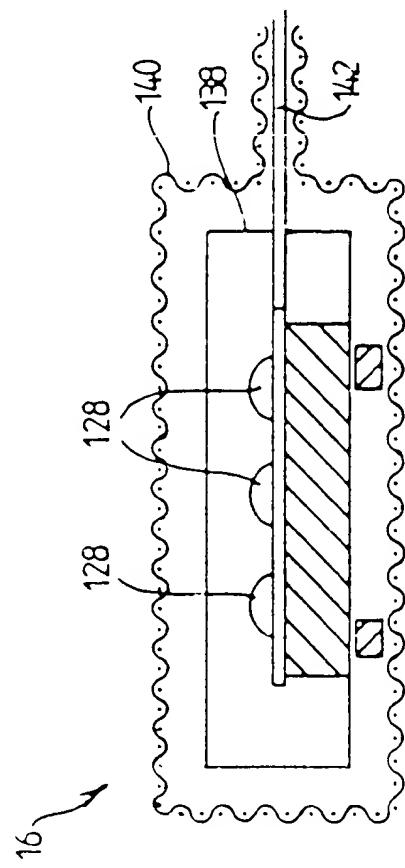
FIG 9
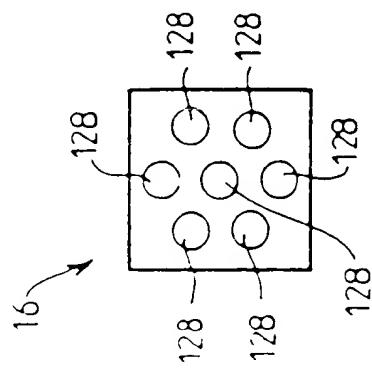
FIG 8

FIG 11

FIG 10

FIG 12

FIG 13A

FIG 13B

FIG 13C

FIG 13D

FIG 13E

FIG 13F

FIG 13G
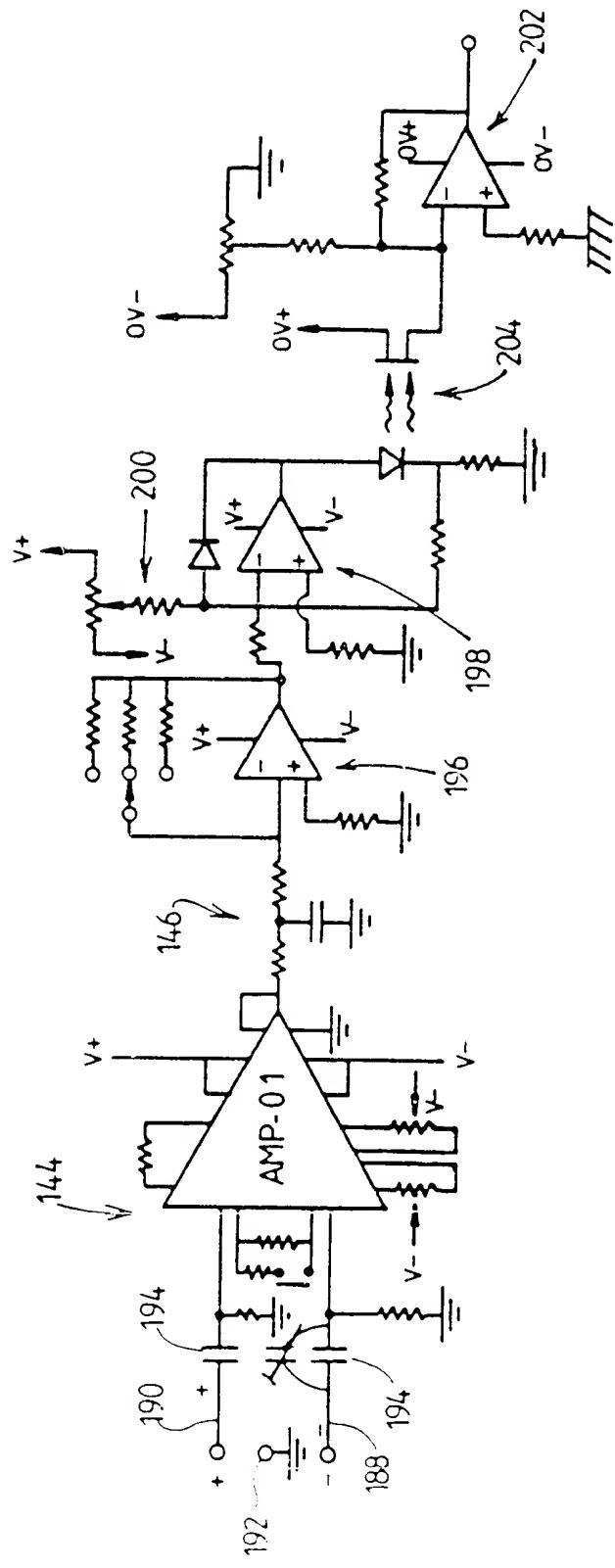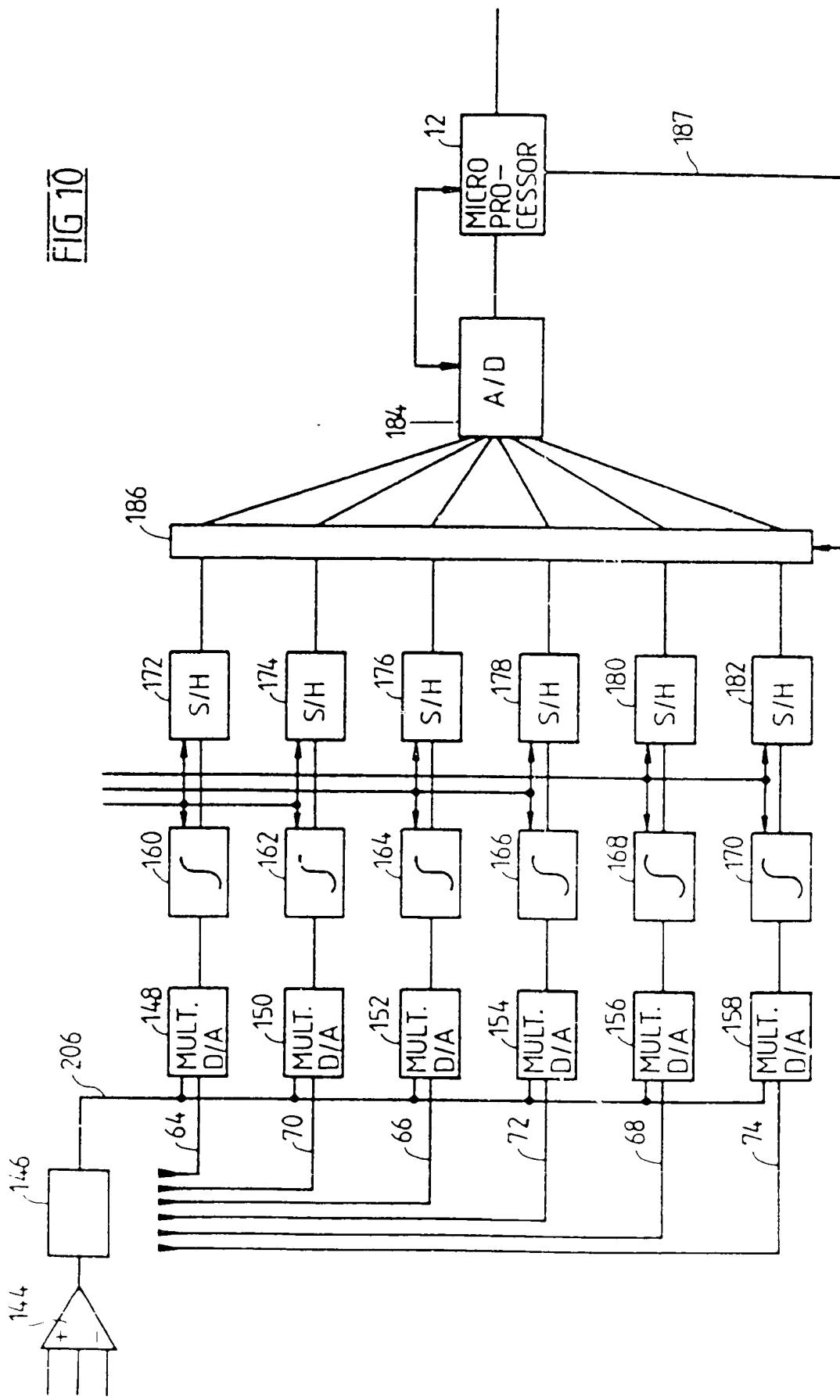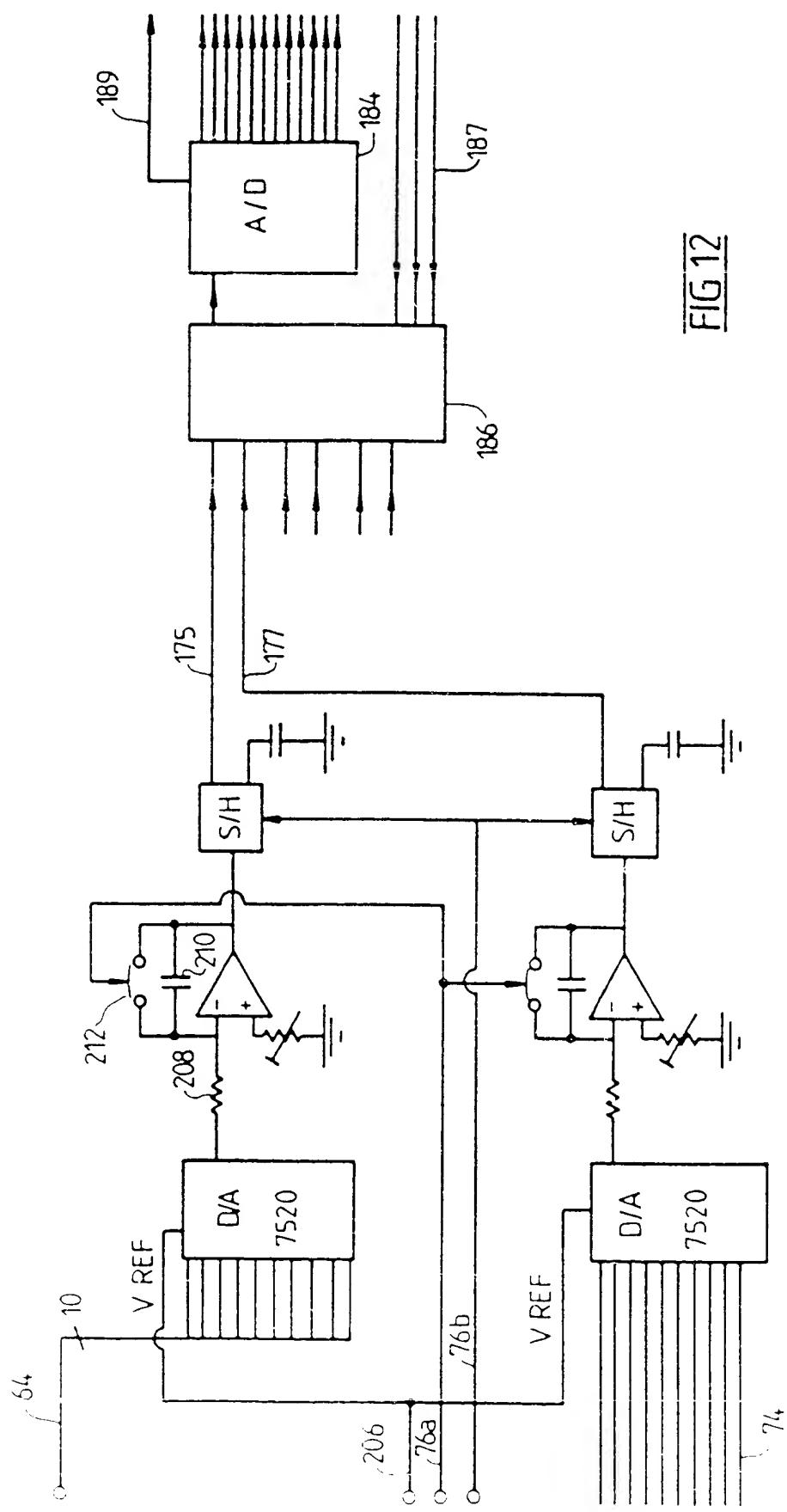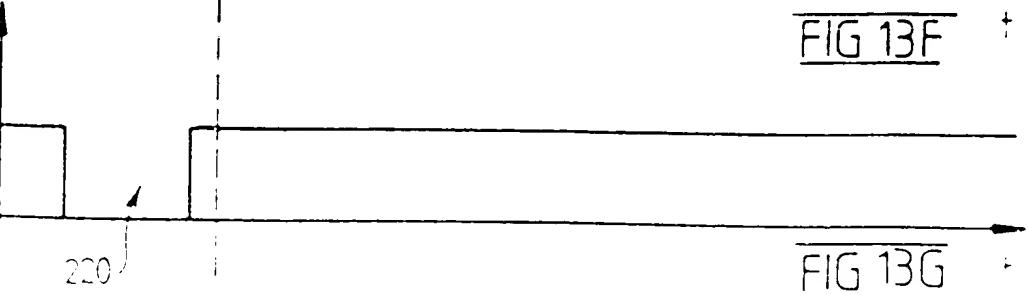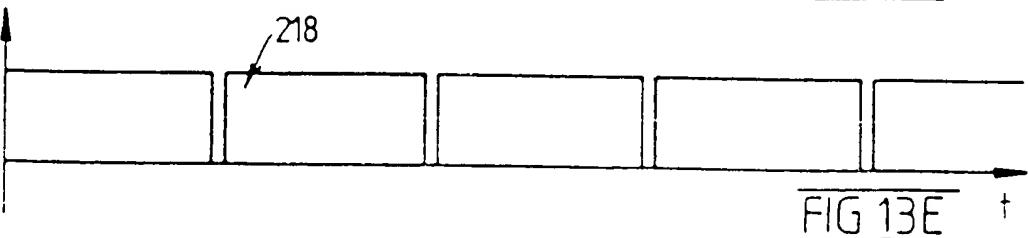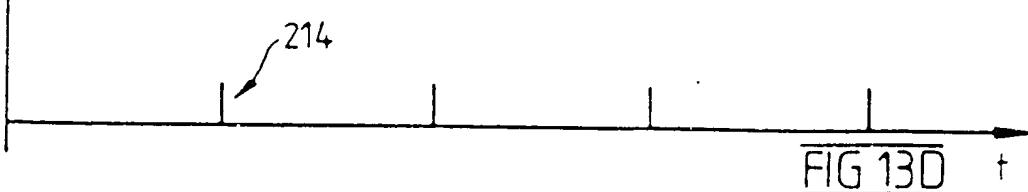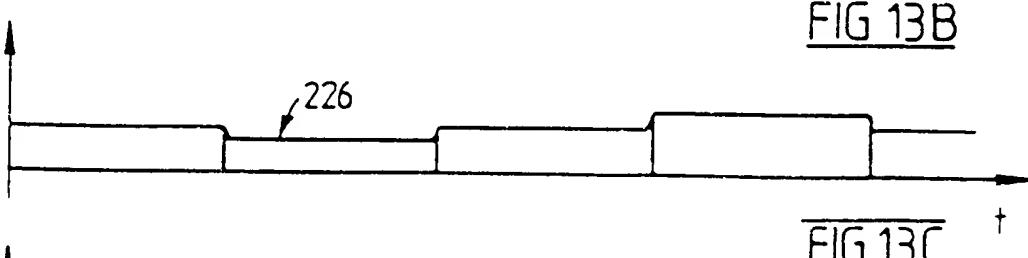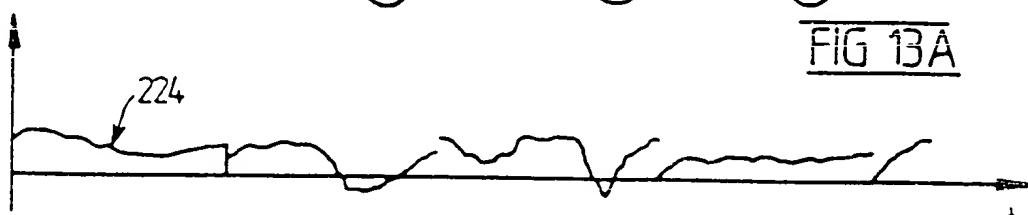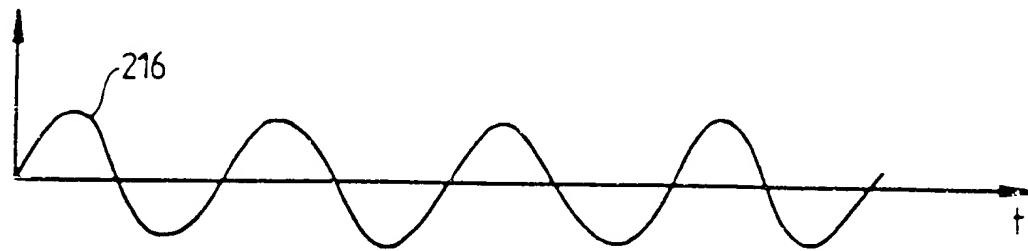
FIG 14
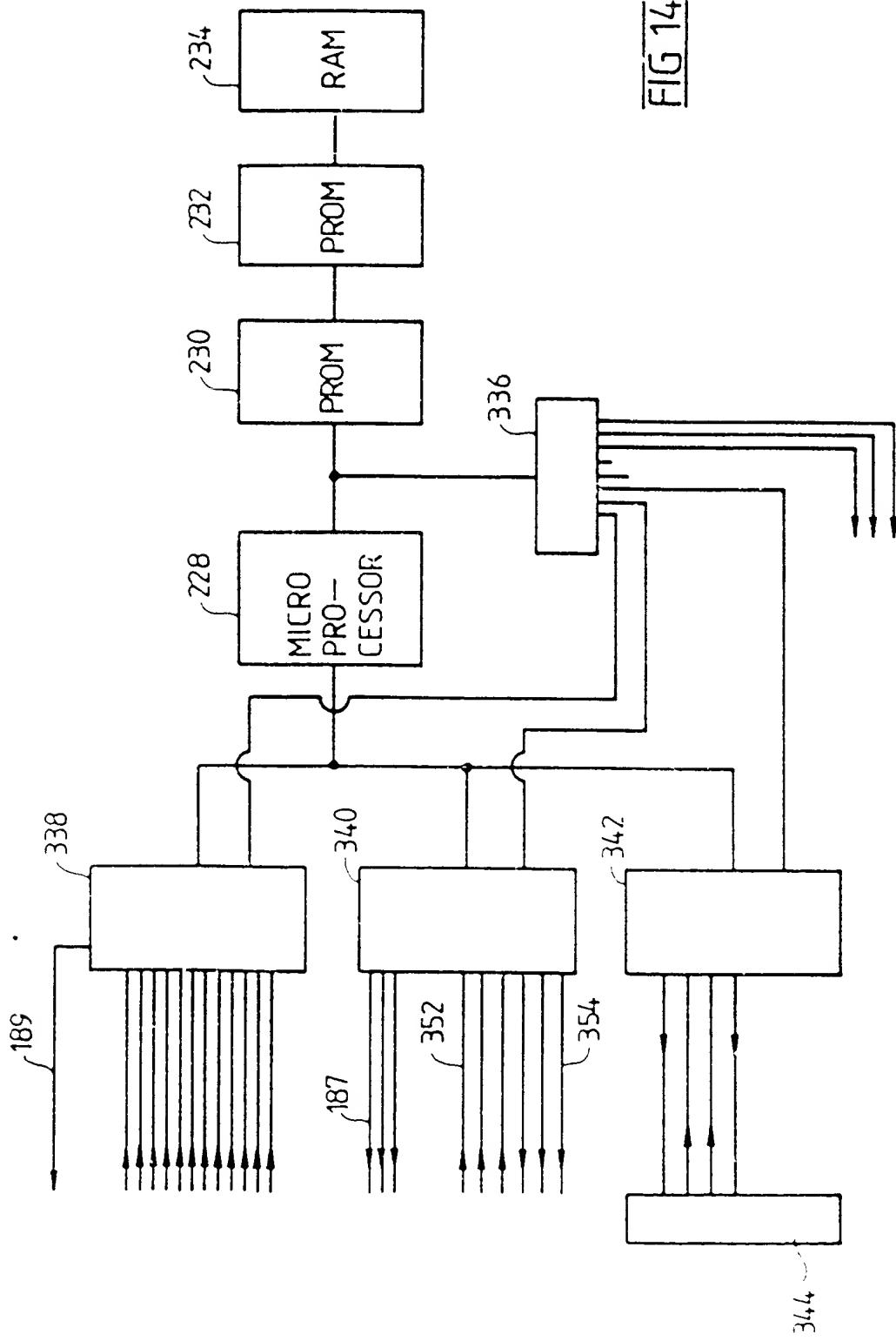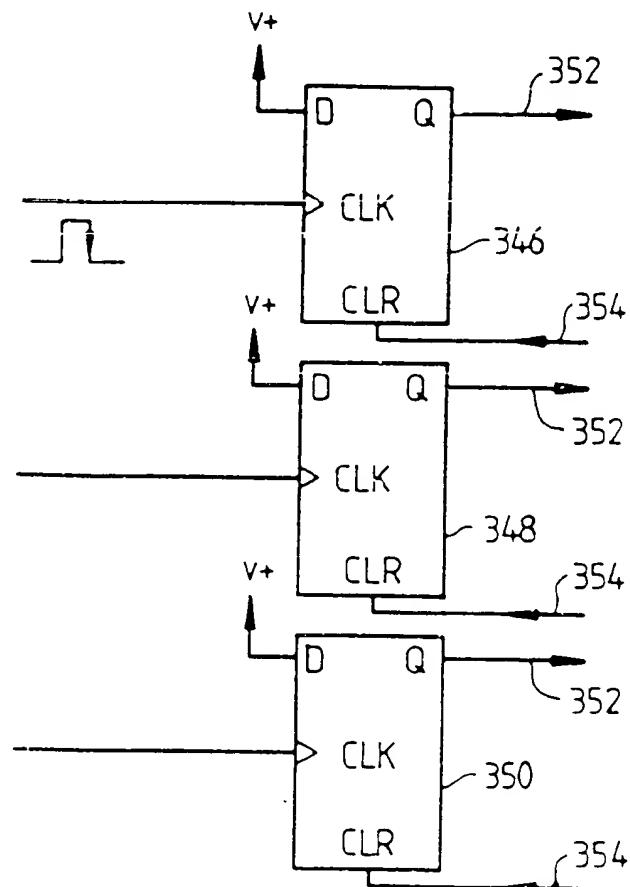
FIG 15

INTERNATIONAL SEARCH REPORT

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl.^{4} A61B 5/04, 3/10

II. FIELDS SEARCHED

Minimum Documentation Searched

Classification System	Classification Symbols
IPC	A61B 5/04, 3/10

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are included in the Fields Searched

AU :   IPC as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
X	US,A, 4493539 (CANNON) 15 January 1985 (15.01.85)	1,13
X	US,A, 3032029 (CUNNINGHAM) 1 May 1962 (01.05.62) See particularly Column 4, lines 11 to 52	1,13
X	US,A, 2860627 (HARDEN) 18 November 1958 (18.11.58) See particularly claim 11	1,13
Y	US,A, 4462411 (RICKARDS) 31 July 1984 (31.07.84)	1,13
Y	EP,A, 13183 (JOHN) 9 July 1980 (09.07.80)	1,13
P,Y	EP,A, 182402 (NEW YORK UNIVERSITY) 28 May 1986 (28.05.86)	1,13
A	US,A, 3809069 (BENNETT) 7 May 1974 (07.05.74)	

* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance, the claimed invention cannot be considered novel or cannot be considered to involve an inventive step
- "Y" document of particular relevance, the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
23 October 1986 (23.10.86)	(04.11.86) 4 NOVEMBER 1986

International Searching Authority	Signature of Authorized Officer
Australian Patent Office	

Form PCT/ISA/210 (second sheet) (January 1985)

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report	Patent Family Members		
US 4462411	AU 79209/82		
EP 13183	CA 1144605	JP 55091337	US 4201224
EP 182402	JP 61154533		

END OF ANNEX